The Mechanics of Tipping Points: A Case of Extreme Elasticity in Expressive Timing

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Abstract Tipping points are an observable and experienced natural phenomenon that has been invoked metaphorically across various domains external to physics. This article introduces the tipping point analogy for musical timing, and presents three case studies illustrating the concept. Quantitative data from recorded performances presented in score-time graphs support the illustrations. The examples show how musicians employ tipping points in performance, and demonstrate how tipping points play on the listener's expectations to elicit emotion. Tipping points form principal tools for the performer's choreography of expectation; the pervasiveness of tipping points in human experience make them an important strategy also for ensemble coordination.

1 Introduction

Musical timing forms the essence of expressive performance. Expressive timing serves to delineate structures and draw attention to musical features [11]. As in the case of stand-up comedy, the right timing can make the difference between a riveting performance and a lackluster one. As illustration of the importance of musical timing, a simple exercise can show that playing a piece with appropriately shaped timing, albeit with many wrong notes, is preferable to playing all the right notes with broken timing.

Research on expressive timing has centered on aspects of phrasing, which are primarily defined by a rise and fall in local tempo or dynamics. Repp [13] showed that these tempo phrase arcs can be described by quadratic functions; Repp [14] further demonstrated that transitions from one tempo to the next can be modeled by cubic functions. Kinematic approaches to modeling tempo showed that a physical body coming to a stop better approximated ritardandi [5]. Taking the locomotive

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analogy a step further, Chew et al. [2] created a driving interface for the shaping of tempo trajectories.

While much work has focused on the ebb and flow of tempo that mark phrasing, little work addresses gestural forms of timing deviations, which can exhibit far more extreme degrees of elasticity. In 2010, Rajagopal observed that local tempo variations at the start of Gould's 1977 and Pogorelich's 1986 performances of Bach's Saraband (BWV 807) resembled a damped harmonic oscillator, thus suggesting that, beyond modeling beats and meter [8, 12], oscillators can also be used to describe tempo fluctuations.

This article introduces the tipping point analogy for musical timing. A musical tipping point is an extreme distortion of the tempo, a musical hyperbole, which extends well beyond the normal pulse and meter. It can be described as a timeless moment of suspended motion, beyond which a small perturbation will tip the balance and set in motion the return of the pulse. Tipping points vary in magnitude; the largest tipping points are relatively rare over the course of a piece, and form the defining moments of a performance.

The next sections will formally present a definition of tipping points, and three case studies illustrating the concept, followed by discussions on the principles of tipping points and how they work. They incorporate material first presented at the Performance Studies Network Conference 2 in Cambridge (UK) [4] and subsequently developed and presented at the International Congress on Music and Mathematics (ICMM) in Puerto Vallarta (Mexico).[1]

2 Tipping Points: A Definition

Tipping points are experienced and observed in the natural world in which we live. We learn and internalize knowledge about tipping points from a young age. Tipping points constitute not only an experienced pattern of behavior and control, but also a conceptualized one [3]. In physics, it is formally defined as the point beyond which the line through the center of gravity lies outside the base of the object. When the line through the center of gravity crosses this tipping point, the object tips over and falls, hence the name.

Socially, tipping points can refer to the line beyond which one's parents (or friends) get very cross. The term tipping point is first used in 1959 in reference to complex systems for which a tipping point is defined as "the critical point in a situation, process, or system beyond which a significant and often unstoppable effect or change takes place" [9]. In his popular book titled *Tipping Point*, Gladwell refers to the origins of the word in epidemiology, where the term refers to the moment when a virus reaches critical mass and an epidemic takes off, and its applications in criminology, and asks the question: What if everything has a tipping point? [6]

[1] The ICMM lecture can be viewed online at https://vimeo.com/112980119.

Tipping points also exist in music. Our focus will be on tipping points in musical timing, which harks back to the basic physics definition of the word.

Music lends itself readily to movement metaphors. With the exception of amorphous music, music generates a pulse that demarcates conceptual units of time. Suppose each conceptualized time unit is a distance, then the time taken to traverse that distance invokes a perception of speed. When less time is taken to travel from one pulse to the next, the music is perceived to be going fast; when more time is taken to traverse the span of a pulse, the music is perceived to be going slowly.

By manipulating the time between pulses, performers can invoke the sensation of acceleration and deceleration; sometimes, the composer notates these speedups and slowdowns in the score (***accelerando***, ***ritardando***).

Suppose that experiencing a piece of music is a journey along a path. Then, the performers' moderating of acceleration and deceleration transforms the topology of the path taken: for example, the slight deceleration followed by an acceleration can simulate the perception of easing into a bend in the road then resuming the original speed; a deeper deceleration simulates the perception of traversing a sharper bend.

This link between music and motion is exploited in [2], where the motion metaphor is made concrete through a driving interface. The ESP interface of [2] considers only a two-dimensional path, which fails to capture expressive gestures that are more extreme and require momentum possible only through the addition of vertical motion. With vertical motion, for example when a ball is tossed into the air or when a train reaches the top of a roller coaster, there is a moment when motion stops, when the object is poised at the brink of change, before the (vertical) direction reverses, and motion resumes.

The tipping point analogy in music refers to these moments in time when the movement is perceived to come to a standstill, and is suspended until a (conceptual) tip initiates the return of the pulse. A tipping point can thus be defined as

> *a timeless moment of suspended stillness, of stasis, beyond which a small perturbation will tip the balance and set in motion the inevitable return of the pulse*.

The tipping point is best illustrated by example. The next section presents three case studies of tipping points in various contexts.

3 Three Case Studies

3.1 Case Study I: Puccini's O Mio Babbino Caro

Singers, especially sopranos and tenors, are well known for their ability to execute extravagant timing gestures, such as tipping points. Consider the excerpt of "O mio babbino caro" from *Gianni Schicchi* by Puccini as shown at the bottom of Fig. 1, with the text and translation (from [15]) as shown below:

Mi struggo e mi tormento!	I am anguished and tormented!
O Dio, vorrei morir!	Oh God, I'd like to die!
Babbo, pietà, pietà!	Papa, have pity, have pity!
Babbo, pietà, pietà!	Papa, have pity, have pity!

A video showing the progression of the eighth note lengths as Maria Callas' performance of a part of this excerpt unfolds can be viewed online at https://vimeo.com/127507105.

Midway through the second line above, "O Dio," the composer writes in a long note on "Dio" that the singer elongates even further (the first major tipping point in Callas' performance) to heighten the poignancy of the plea, before the anguished "vorrei morir." At the next line, "Babbo, pietà, pietà," when "pietà" is desperately reiterated with an octave leap up, the soprano lingers on the high note, delaying the expected registral return. There is a dramatic pause at the end of the line (another major tipping point), before the final "Babbo, pietà, pietà."

Figure 1 shows the eighth note lengths of Maria Callas' performance for the entire excerpt. The tipping points in Callas' performance are indicated by red cue balls, with the size of the cue ball reflecting the magnitude of the tipping point. Superimposed on Callas' performance are plots of lengths of the same eighth notes in performances by Kathleen Battle and Kiri the Kanawa, showing differences in the narrative strategies employed by the three performers.

In this case study, tipping points are used to prolong expectation (for example, by delaying the expected registral return following an upward melodic leap), thus creating drama, exaggerating emotion cues, and heightening poignancy.

3.2 Case Study II: Strauss' Burleske

A prototypical place for employing or finding tipping points is at the ends of cadenzas. In the classical concerto, the cadenza, whether improvised or composed, is an elaboration of the V chord in the V-I progression at an important turning point in the piece. Figure 2 shows a two-piano arrangement (with the orchestra part in the second piano) of the cadenza in Strauss' *Burleske* in D minor for Piano and Orchestra; Fig. 3 shows the tipping points. With D as the tonic, A is the dominant (V). Prominent octave A's are generously sprinkled throughout the entire cadenza, with the intensity of the chordal trills and sweeping arpeggios coming to a head at the first tipping point (indicated by the small cue ball). The tension continues to build as the V has not yet resolved to the expected I chord. Finally, at the last A, a lone voice in the right hand, we arrive at the moment of reckoning, of the main tipping point, auguring inevitable change and release after prolonged suspense.

A video at https://vimeo.com/70618400 shows the bar durations in Chew's performance of the cadenza of Strauss' *Burleske* synchronized with the audio. Figure 3 shows the bar lengths of Chew's performance annotated with the two tipping points: a smaller one, and a larger one. Superimposed on Chew's' performance are plots

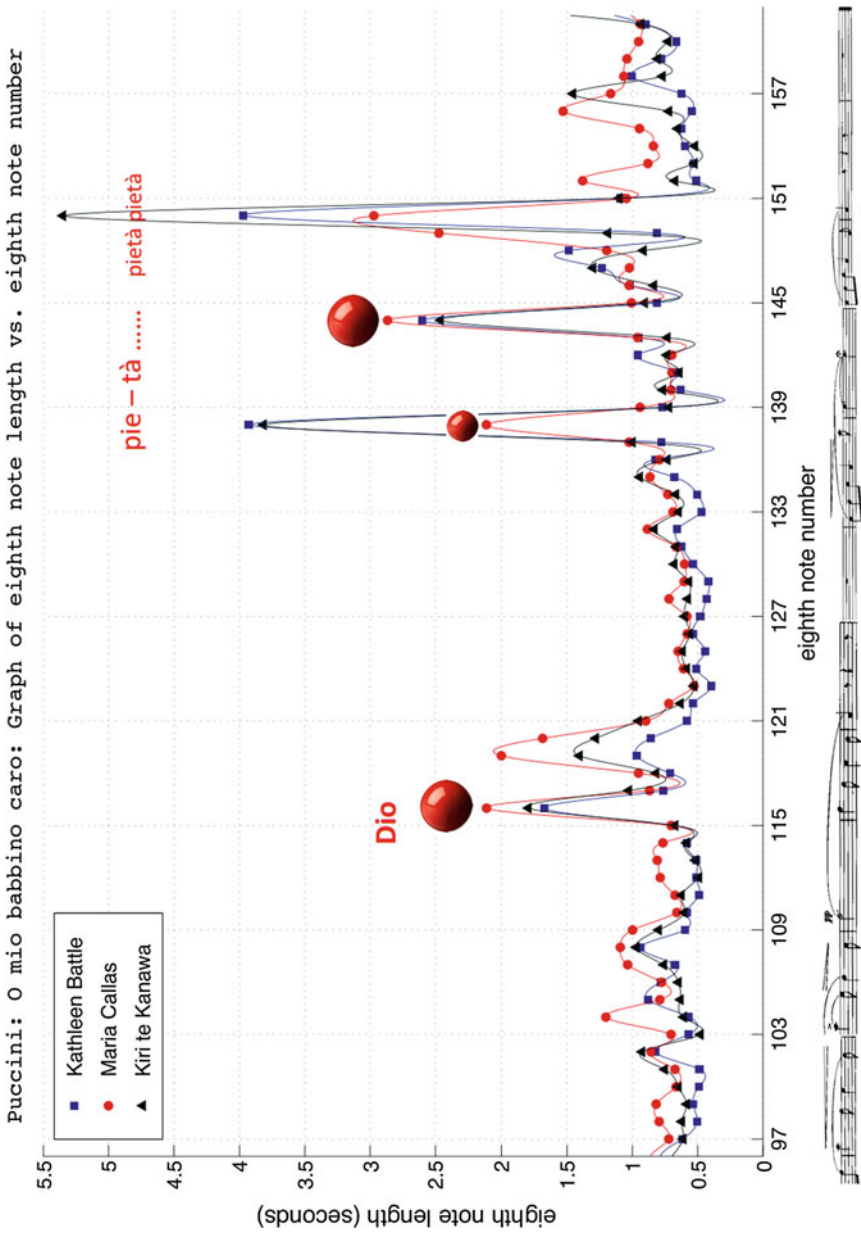

Fig. 1 Plots of eighth note lengths in performances of Puccini's "O Mio Babbino Caro" by Kathleen Battle, Maria Callas, and Kiri te Kanawa, with tipping points in Callas' performance highlighted. Vertical grid lines mark the start of each bar

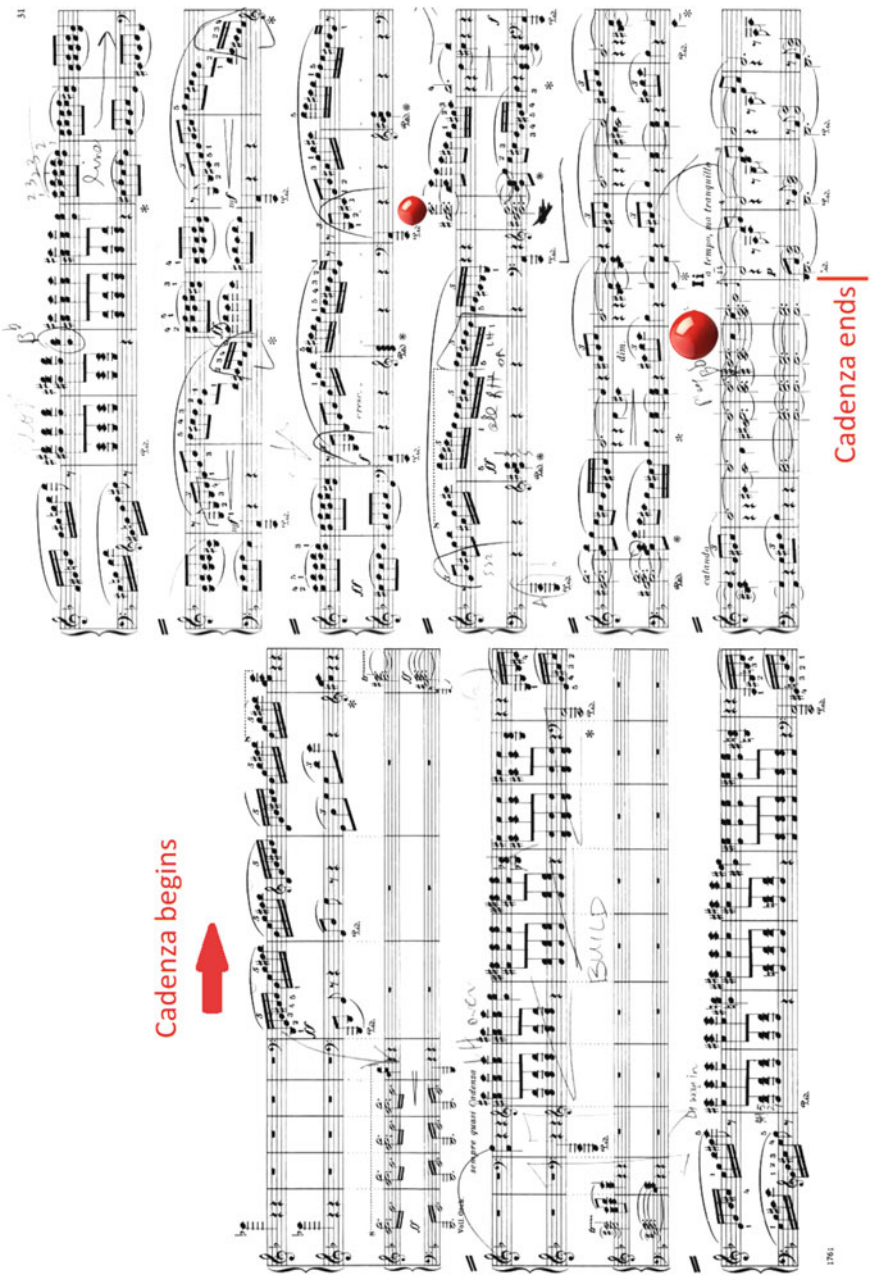

Fig. 2 Score of the cadenza in Strauss' *Burleske* for Piano and Orchestra

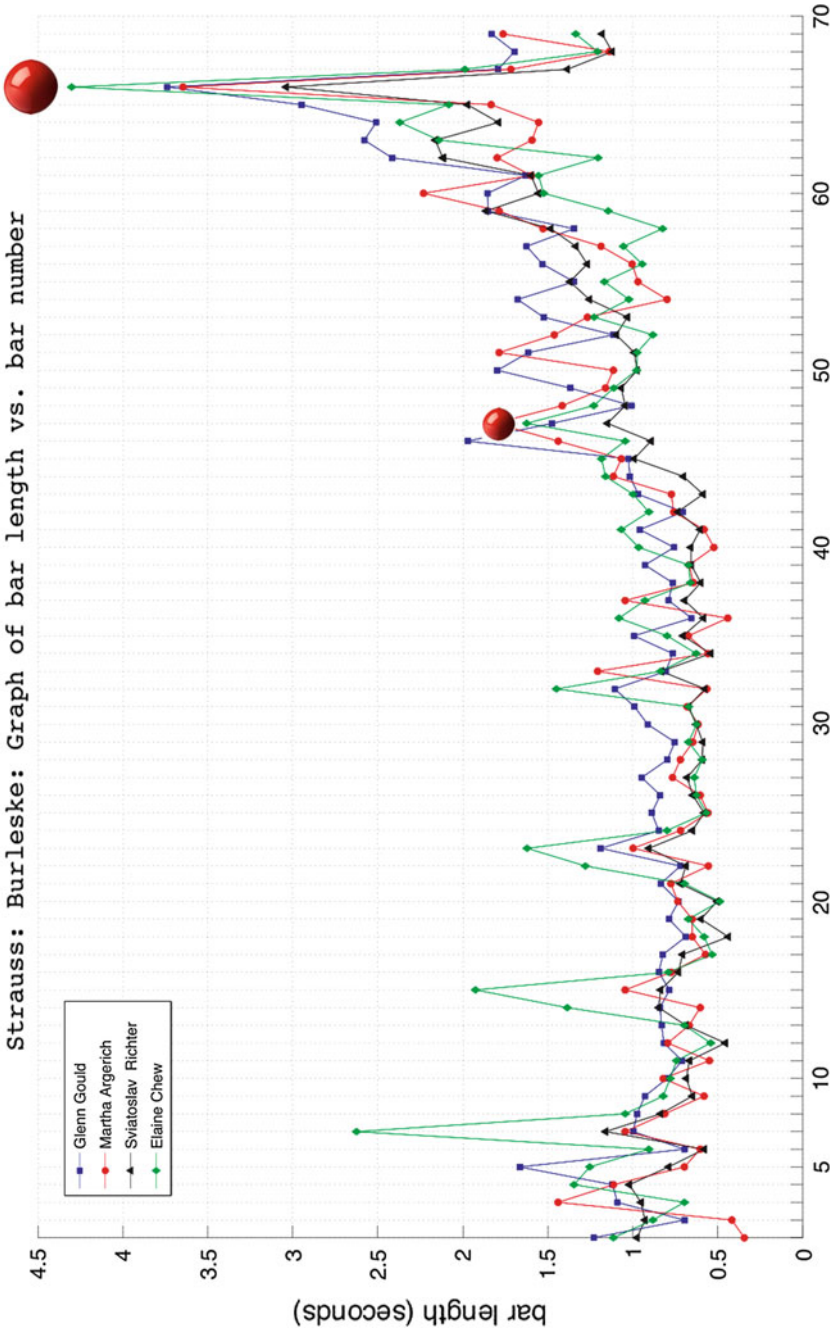

Fig. 3 Plots of bar lengths in performances of the candenza in Strauss' *Burleske* by Glenn Gould, Martha Argerich, Sviatoslav Richter and Elaine Chew, with tipping points in Chew's performance (which concur with Argerich's and Richter's) highlighted. Vertical grid lines mark the start of each bar

of lengths of the same bars in performances by Martha Argerich, Glenn Could, and Sviatoslav Richter.

Here, the main tipping point, a cadential tipping point, signals the release after the prolonged suspense, auguring inevitable change and augmenting the tonal expectations. Additionally, the tipping point also coordinates the return of the orchestra and that of the lyrical theme.

3.3 Case Study III: Kreisler's Schon Rosmarin

The final case study shows an unusual example of a tipping point at the beginning of a piece. Consider the excerpt of Kreisler's "Schön Rosmarin" as shown at the bottom of Fig. 4. Above the score is a graph showing the length of each beat in Kreisler's performance of the excerpt. An animation of a version of this graph with the audio can be viewed at https://vimeo.com/127499857.

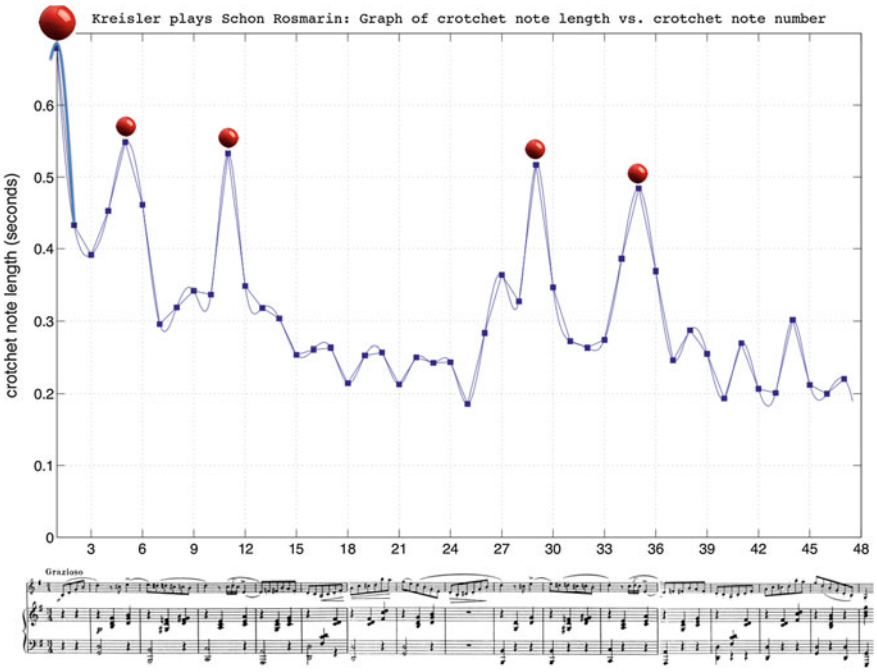

Fig. 4 Plot of beat (crotchet note) lengths in Kreisler's performance of his "Schön Rosmarin", with tipping points highlighted. Vertical grid lines mark the start of each bar (figure reproduced in p. 350 of [1])

As can be seen (and heard), Kreisler begins the piece with a tipping point, before cascading down to the nominal beat length (or tempo), embellishing two melodic target note pairs with small tipping points along the way, in a playful simulation of gravity-defying moves.

4 Discussion and Conclusions

In this paper, I have presented a definition of tipping points in music, in particular, in musical timing. Three case studies illustrated the concept, demonstrating how tipping points can generate expectation (and thus elicit emotion), facilitate and augment cathartic release and coordinate returns, and playfully simulate gravity-defying moves.

In each case, the extreme elasticity of the tipping points are possible because there is full knowledge and maximum expectation of what is to come. At these points of maximum certainty, information is minimized and entropy is low. Because expectation is peaked, and the outcome is fixed, the performer can play freely with time to further pique the listener's expectations.

Musical expectations can be schematic (based on observed patterns) or veridical (based on knowledge of a specific piece, e.g. "Happy Birthday") [7]. Schematic expectations include those pertaining to tonality—such as the tendency to return to a stable state as V needing to resolve to I in a perfect cadence—and melody—such as the ascending leap-descending step and the post-skip reversal tendencies.

Tipping points introduce a piquant element of uncertainty in situations possessing absolute certainty. They delay highly expected outcomes in ways that mix predictability with indeterminacy—for example, the listener does not know when the (time) suspension will tip. Thus, tipping points heighten expectation, increase tension, and elicit emotion.

As noted in [7], Meyer argued in [10] that the emotion content of music arises primarily through the composer's choreography of expectation—by setting up, delaying, thwarting, or delivering on expectations. As shown by the tipping point case studies, the emotion content of music arises through not only the composer's, but also the performer's, choreography of expectation.

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